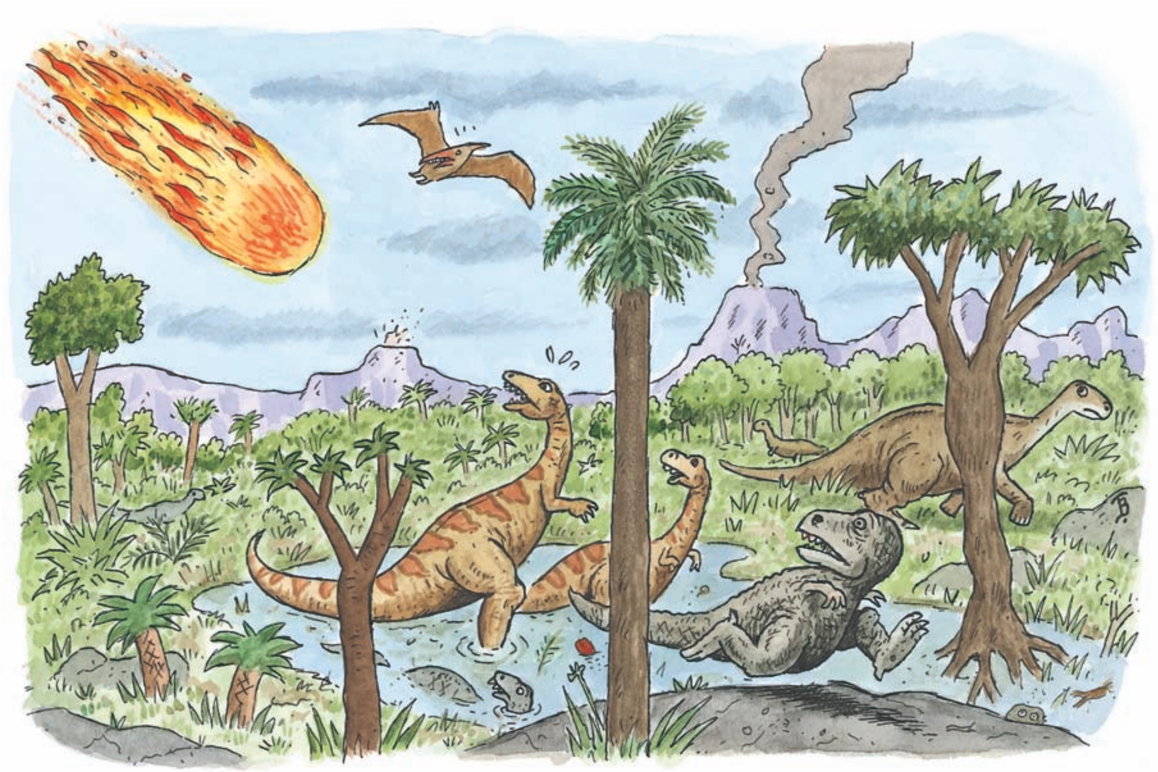
Activity 4 Impact Events and the Earth System



Goals

In this activity you will:

- Investigate the mechanics of an impact event and make scale drawings of an impact crater.
- Calculate the energy (in joules) released when an asteroid collides with Earth.
- Compare natural and man-made disasters to the impact of an asteroid.
- Understand the consequences to your community should an impact event occur.
- Investigate the chances for an asteroid or comet collision.

Think about It

Meteor Crater in Arizona is one of the best-preserved meteor craters on Earth. It is 1.25 km across and about 4 km in circumference. Twenty football games could be played simultaneously on its floor, while more than two million spectators observed from its sloping sides.

- How large (in diameter) do you think the meteor was that formed Meteor Crater?
- How would the impact of the meteor have affected living things near the crater?

What do you think? Record your ideas about these questions in your *EarthComm* notebook. Be prepared to discuss your responses with your small group and the class.

Investigate

1. Given the following information, calculate the energy released when an asteroid collides with Earth:

   - The spherical, iron–nickel asteroid has a density of 7800 kg/m^3.
   - It is 40 m in diameter.
   - It has a velocity of 20,000 m/s relative to the Earth.

   Note: It is very important to keep track of your units during these calculations. You will be expressing energy with a unit called a “joule.” A joule is 1 kg m^2/s^2.

   a) Find the volume of the asteroid in cubic meters. The equation for the volume of a sphere is as follows:

   $$V = \frac{4}{3}\pi r^3$$

   where V is volume of the sphere, and r is the radius of the sphere.

   b) Multiply the volume by the density to find the total mass of the asteroid.

   c) Calculate the energy of the asteroid. Because the asteroid is moving, you will use the equation for kinetic energy, as follows:

   $$KE = \frac{1}{2}mv^2$$

   where KE is kinetic energy,
   m is the mass, and
   v is the velocity.

   Express your answer in joules. To do this express mass in kilograms, and velocity in meters per second.

   For some perspective, a teenager uses over 10,000 kJ (kilojoules) of energy each day. (There are 1000 J (joules) in a kilojoule.)

2. The combination of calculations that you just performed can be summarized as:

   $$\textbf{Energy} = \frac{2}{3}\pi\rho r^3 v^2$$

   where r is the radius,
   ρ is the density, and
   v is the velocity of the object.

   a) Suppose an object makes an impact with the Earth at 10 times the velocity of another identical object. By what factor will the energy of the object increase?

   b) Suppose an object makes an impact with the Earth, and it has 10 times the radius of another object traveling at the same speed. By what factor will the energy of the object increase?

   c) How do these relationships help to explain how small, fast-moving objects can release a tremendous amount of energy as well as larger yet slower-moving objects?

3. The asteroid described in **Step 1** above was the one responsible for Meteor Crater in Arizona.

   a) Copy the following table into your notebook. Enter your calculation for Meteor Crater.

   b) Calculate the energy released by the impacts shown in the table.

Object	Radius (m)	Density (kg/m^3)	Impact Velocity (m/s)	Energy (joules)	Richter Scale Magnitude Equivalent
Asclepius	100	3000	30,000		
Comet Swift-Tuttle	1000	1000	60,000		
Chicxulub impactor	5000	3000	32,000		
SL9 Fragment Q	2150	1000	60,000		
Meteor Crater	20	7800	20,000		

Note:

- Asclepius is an asteroid that passed within 690,000 km of Earth in 1989.
- Comet Swift-Tuttle is a future threat to the Earth–Moon system, having passed Earth in 1992 and being scheduled for return in 2126.
- SL9 Fragment Q is a fragment of Comet Shoemaker-Levy that impacted Jupiter in 1994.
- Chicxulub impactor is the name of the asteroid that triggered the extinction of the dinosaurs 65 million years ago.

4. Use the table below to compare the energy from all these events to known phenomena.

   a) In your notebook, explain how the energies of these four impact events compare to some other known phenomena.

Phenomena	Kinetic Energy (joules)
Annual output of the Sun	10^{34}
Severe earthquake	10^{18}
100-megaton hydrogen bomb	10^{17}
Atomic bomb	10^{13}

5. Make a scale drawing of the Chicxulub impactor compared with Earth. The diameter of the Earth is 12,756 km.

   a) If you made the diameter of the Chicxulub impactor 1 mm, what would the diameter of the Earth be?

   b) If you made the diameter of the Chicxulub impactor 0.5 mm, which is probably about as small as you can draw, what would the diameter of the Earth be?

6. How do these impact events compare with the energy released in an earthquake? If you have a calculator capable of handling logarithms, answer the following questions:

   a) Calculate the Richter scale equivalent of the energy released by the four impact events. Use the following equation:

   $$M = 0.67 \log_{10}E - 5.87$$

   where M is the equivalent magnitude on the Richter scale, and E is the energy of the impact, in joules.

   b) How do your results compare with the table below, which shows the five greatest earthquakes in the world between 1900 and 1998? Which impacts exceed the world's greatest earthquakes?

Location	Year	Magnitude
Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Andreanof Islands, Aleutian Islands	1957	9.1
Kamchatka	1952	9.0
Off the Coast of Ecuador	1906	8.8

Reflecting on the Activity and the Challenge

You have calculated the energy released when asteroids of different sizes hit the Earth's surface, and you have compared these to other energy-releasing events. This comparison will be helpful as you explain the hazards associated with an impact in your **Chapter Challenge** brochure.

Digging Deeper

ASTEROIDS AND COMETS

Asteroids

Asteroids are rocky bodies smaller than planets. They are leftovers from the formation of the solar system. In fact, the early history of the solar system was a period of frequent impacts. The many scars (impact craters) seen on the Moon, Mercury, Mars, and the moons of the outer planets are the evidence for this bombardment. Asteroids orbit the Sun in very elliptical orbits with inclinations up to 30°. Most asteroids are in the region between Jupiter and Mars called the asteroid belt. There are probably at least 100,000 asteroids 1 km in diameter and larger. The largest, called Ceres, is about 1000 km across. Some of the asteroids have very eccentric orbits that cross Earth's orbit. Of these, perhaps a few dozen are larger than one kilometer in diameter. As you learned in the activity, the energy of an asteroid impact event increases with the cube of the radius. Thus, the larger asteroids are the ones astronomers worry about when they consider the danger of collision with Earth.

Figure 1 Image of the asteroid Ida, which is 58 km long and 23 km wide.

The closest recent approach of an asteroid to Earth was Asteroid 1994 XM 11. On December 9, 1994, the asteroid approached within 115,000 km of Earth. On March 22, 1989 the asteroid 4581 Asclepius came within 1.8 lunar distances, which is close to 690,000 km. Astronomers think that asteroids at least 1 km in diameter hit Earth every few hundred million years. They base this upon the number of impact craters that have been found and dated on Earth. A list of asteroids that have approached within two lunar distances of Earth (the average distance between Earth and the Moon) is provided in *Table 1* on the following page. Only close-approach distances less than 0.01 AU for asteroids are included in this table.

Table 1 Asteroids with Close-Approach Distances to Earth			
Name or Designation	**Date of Close Earth Approach**	**Distance**	
		(AU)	**(LD)**
1994 XM1	1994–Dec–09	0.0007	0.3
1993 KA2	1993–May–20	0.001	0.4
1994 ES1	1994–Mar–15	0.0011	0.4
1991 BA	1991–Jan–18	0.0011	0.4
1996 JA1	1996–May–19	0.003	1.2
1991 VG	1991–Dec–05	0.0031	1.2
1999 VP11	1982–Oct–21	0.0039	1.5
1995 FF	1995–Apr–03	0.0045	1.8
1998 DV9	1975–Jan–31	0.0045	1.8
4581 Asclepius	1989–Mar–22	0.0046	1.8
1994 WR12	1994–Nov–24	0.0048	1.9
1991 TU	1991–Oct–08	0.0048	1.9
1995 UB	1995–Oct–17	0.005	1.9
1937 UB (Hermes)	1937–Oct–30	0.005	1.9
1998 KY26	1998–Jun–08	0.0054	2.1

(AU) – Astronomical distance Unit: 1.0 AU is roughly the average distance between the Earth and the Sun.
(LD) – Lunar Distance unit: 1.0 LD is the average distance from the Earth to the Moon (about 0.00257 AU).

Most (but not all) scientists believe that the extinction of the dinosaurs 65 million years ago was caused by the impact of an asteroid or comet 10 km in diameter. Such a large impact would have sent up enough dust to cloud the entire Earth's atmosphere for many months. This would have blocked out sunlight and killed off many plants, and eventually, the animals that fed on those plants. Not only the dinosaurs died out. About 75% of all plants and animals became extinct. One of the strong pieces of evidence supporting this hypothesis is a 1-cm-thick layer of iridium-rich sediment about 65 million years old that has been found worldwide. Iridium is rare on Earth but is common in asteroids.

Our planet has undergone at least a dozen mass-extinction events during its history, during which a large percentage of all plant and animal species became extinct in an extremely short interval of geologic time. It is likely that at least some of these were related to impacts. It is also likely that Earth will suffer another collision sometime in the future. NASA is currently forming plans to discover and monitor asteroids that are at least 1 km in size and with orbits that cross the Earth's orbit. Asteroid experts take the threat from asteroids very seriously, and they strongly suggest that a program of systematic observation be put into operation to predict and, hopefully avoid an impact.

Comets

Comets are masses of frozen gases (ices) and rocky dust particles. Like asteroids, they are leftovers from the formation of the solar system. There are many comets in orbit around the Sun. Their orbits are usually very eccentric with large inclinations. The orbits of many comets are very large, with distances from the Sun of greater than 20,000 astronomical units (AU). The icy head of a comet (the nucleus) is usually a few kilometers in diameter, but it appears much larger as it gets closer to the Sun. That's because the Sun's heat vaporizes the ice, forming a cloud called a coma. Radiation pressure and the action of the **solar wind** (the stream of fast-moving charged particles coming from the Sun) blow the gases and dust in the coma in a direction away from the Sun. This produces a tail that points away from the Sun even as the comet moves around the Sun. Halley's Comet, shown in *Figure 2*, is the best known of these icy visitors. It rounds the Sun about every 76 years, and it last passed by Earth in 1986.

Figure 2 Halley's Comet last appeared in the night sky in 1986.

Comets have collided with the Earth since its earliest formation. It is thought that the ices from comet impacts melted to help form Earth's oceans. In 1908 something hit the Earth at Tunguska, in Siberian Russia. It flattened trees for hundreds of miles, and researchers believe that the object might have been a comet. Had such an event occurred in more recent history in a more populated area, the damage and loss of life would have been enormous. A list of comets that have approached within less than 0.11 AU of Earth is provided in *Table 2* on the following page.

Geo Words

solar wind: a flow of hot charged particles leaving the Sun.

Geo Words

meteoroid: a small rock in space.

meteor: the luminous phenomenon seen when a meteoroid enters the atmosphere (commonly known as a shooting star).

meteorite: a part of a meteoroid that survives through the Earth's atmosphere.

Table 2 Close Approaches of Comets

Name	Designation	Date of Close Earth Approach	Distance (AU)	(LD)
Comet of 1491	C/1491 B1	1491–Feb–20	0.0094	3.7*
Lexell	D/1770 L1	1770–Jul–01	0.0151	5.9
Tempel-Tuttle	55P/1366 U1	1366–Oct–26	0.0229	8.9
IRAS-Araki-Alcock	C/1983 H1	1983–May–11	0.0313	12.2
Halley	1P/ 837 F1	837–Apr–10	0.0334	13
Biela	3D/1805 V1	1805–Dec–09	0.0366	14.2
Comet of 1743	C/1743 C1	1743–Feb–08	0.039	15.2
Pons-Winnecke	7P/	1927–Jun–26	0.0394	15.3
Comet of 1014	C/1014 C1	1014–Feb–24	0.0407	15.8*
Comet of 1702	C/1702 H1	1702–Apr–20	0.0437	17
Comet of 1132	C/1132 T1	1132–Oct–07	0.0447	17.4*
Comet of 1351	C/1351 W1	1351–Nov–29	0.0479	18.6*
Comet of 1345	C/1345 O1	1345–Jul–31	0.0485	18.9*
Comet of 1499	C/1499 Q1	1499–Aug–17	0.0588	22.9*
Schwassmann-Wachmann 3	73P/1930 J1	1930–May–31	0.0617	24

* Distance uncertain because comet's orbit is relatively poorly determined.
(AU) – Astronomical distance Unit: 1.0 AU is roughly the average distance between the Earth and the Sun.
(LD) – Lunar Distance unit: 1.0 LD is the average distance from the Earth to the Moon (about 0.00257 AU).

Meteoroids, Meteors, and Meteorites

Meteoroids are tiny particles in space, like leftover dust from a comet's tail or fragments of asteroids. Meteoroids are called **meteors** when they enter Earth's atmosphere, and **meteorites** when they reach the Earth's surface. About 1000 tons of material is added to the Earth each year by meteorites, much of it through dust-sized particles that settle slowly through the atmosphere. There are several types of meteorites. About 80% that hit Earth are stony in nature and are difficult to tell apart from Earth rocks. About 15% of meteorites consist of the metals iron and nickel and are very dense. The rest are a mixture of iron–nickel and stony material. Most of the stony meteorites are called chondrites. Chondrites may represent material that

was never part of a larger body like a moon, a planet, or an asteroid, but instead are probably original solar-system materials.

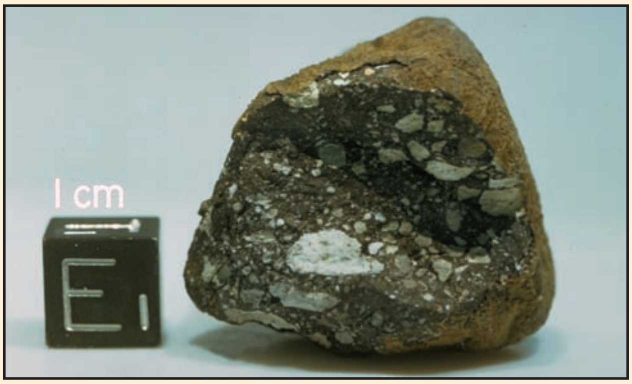


Figure 3 Lunar meteorite.

Check Your Understanding

1. Where are asteroids most abundant in the solar system?
2. How might a major asteroid impact have caused a mass extinction of the Earth's plant and animal species at certain times in the geologic past?
3. Why do comets have tails? Why do the tails point away from the Sun?
4. What are the compositions of the major kinds of meteorites?

Understanding and Applying What You Have Learned

1. Look at the table of impact events shown in the **Investigate** section. Compare the densities of the object that formed Meteor Crater and SL9 Fragment Q from the Shoemaker-Levy Comet. Use what you have learned in this activity to explain the large difference in densities between the two objects.
2. If an asteroid or comet were on a collision course for Earth, what factors would determine how dangerous the collision might be for your community?
3. How would an asteroid on a collision course endanger our Earth community?
4. Comets are composed largely of ice and mineral grains. Assume a density of 1.1 g/cm^3:
   a) How would the energy released in a comet impact compare to the asteroid impact you calculated in the **Investigate** section? (Assume that the comet has the same diameter and velocity as the asteroid.)
   b) Based upon your calculation, are comets dangerous if they make impact with the Earth? Explain your response.
5. From the information in the **Digging Deeper** reading section, and what you know about the eccentricities and inclinations of asteroid orbits, how likely do you think it is that an asteroid with a diameter of 1 km or greater will hit the Earth in your lifetime? Explain your reasoning. Can you apply the same reasoning to comets?
6. Add the asteroid belt to the model of the solar system you made in the first activity. You will need to think about how best to represent the vast number of asteroids and their wide range of sizes. Don't forget to add in some samples of Earth-approaching asteroids and the orbit of one or two comets.

Preparing for the Chapter Challenge

Assume that scientists learn several months before impact that a large asteroid will hit near your community. Assume that you live 300 km from the impact site. What plans can your family make to survive this disaster? What are some of the potential larger-scale effects of an asteroid impact? Work with your group to make a survival plan. Present your group's plan to the entire class. Be sure to record suggestions made by other groups. This information will prove useful in completing the **Chapter Challenge.**

Inquiring Further

1. **Impact craters on objects other than the Earth**

   In an earlier activity you studied impact sites on the Moon. Look at Mercury, Mars, and the moons of Saturn, Uranus, and Neptune to see other examples of impact craters in the solar system. How are these craters similar to Meteor Crater? How are they different?

2. **Modeling impact craters**

   Simulate an asteroid or comet hitting the Earth. Fill a shoebox partway with plaster of Paris. When the plaster is almost dry, drop two rocks of different sizes into it from the same height. Carefully retrieve the rocks and drop them again in a different place, this time from higher distance. Let the plaster fully harden, then examine, and measure the craters. Measure the depth and diameter and calculate the diameter-to-depth ratio. Which is largest? Which is deepest? Did the results surprise you?

3. **Earth-approaching asteroids**

   Do some research into current efforts by scientists to map the orbits of Earth-approaching asteroids? Visit the *EarthComm* web site to help you get started with your research. How are orbits determined? What is the current thinking among scientists about how to prevent impacts from large comets or asteroids?

4. **Barringer Crater**

   Research the Barringer Crater (Meteor Crater). The crater has been named for Daniel Moreau Barringer, who owned the property that contains the crater. Explain how scientists used Barringer Crater to understand how craters form. Study the work of Dr. Eugene Shoemaker, who was one of the foremost experts on the mechanics of impact cratering.

Wear goggles while modeling impact craters. Work with adult supervision to complete the activity.